Author version of a paper published in: International Journal of Sociotechnology and Knowledge Development, volume 9 (4): pp. 28-42 (2017)

From Human-Centered Design to disabled user & ecosystem centered design in case of assistive interactive systems

Marine Guffroy[1], Nadine Vigouroux[2], Christophe Kolski[3], Fréderic Vella[2], Philippe Teutsch[1]
[1]*CREN Le Mans Université, France*

[2]*IRIT, UMR CNRS 5505, Université Toulouse 3, France*

[3]*LAMIH, UMR CNRS 8201, Université de Valenciennes et du Hainaut-Cambrésis, France*

ABSTRACT

This article aims to revisit and to adapt the Norman's theory of action (Norman, 1986) by focusing on the design of interactive systems for disabled people. The background section demonstrates that there is a need to include all the stakeholders involved in the environment of the disabled person in the design process, constituting his or her ecosystem. Then the adaptation of the Norman's theory action, considering explicitly the ecosystem is justified; examples of the both role of the disabled people and members of his/her ecosystem are given for the seven components of Norman's model. Two cases studies are after presented to illustrate the crucial role of the ecosystem in case of assistive interactive system design. The benefits of taking into account the ecosystem in the design of interactive systems for disabled persons are discussed. The paper ends by a conclusion and research perspectives.

Keywords: Norman's model, User-Centered Design, ecosystem of stakeholders, disabled person, assistive system, inclusive technological solution

INRODUCTION

Many studies shown that high abandonment rate of assistive technologies and/or interactive systems may be important because no sufficient representation from potential users. Philips and Zhao (1993) related that almost one third of all the user's assistive technologies were completely abandoned. This high rate of abandonment ascertained that a large percent of devices (assistive technologies, interactive systems, physical devices, etc.) are not meeting user' needs. Riemer-Ress and Wacker (1999) reported additional explanations such as environmental barriers dependent of the disability and also fear of technology. Sometimes low performance of interactive systems or their inability to adapt to new user' functional abilities that are inevitably imposed by the development of impairment are also reported within the literature.
It is well established that the User-Centered Design (UCD) approach to design assistive and rehabilitation technologies might represent an important way to improve accessibility, usability, acceptability and appropriation.

The Norman's model (Norman, 1986), (Norman, 2013) is a well-known conceptual model used for interactive system design. It helps the designers to understand the stages followed by the users when interacting with a system, and may incite them to involve explicitly the user in the design process. This model is generic and is centered mainly on only one person: the end 'user of the interactive system.
However, the design of assistive and rehabilitation system for disabled people needs to identify the right stakeholders involved in the UCD for informing the design process and to express their needs, to report their behavior in the activity daily life, to acquire a mental model of the system as defined by (Norman & Draper, 1986). Disabled end users may have difficulties to express their needs, other stakeholders such as caregivers, family members, teachers, specialized educators, etc., have to collaborate in the different design stages (Marti & Bannon, 2009) (Markopoulos et al., 2011). More their needs have also to be taken into account as direct or indirect users of the future systems in the context of common activities with the disabled person. These stakeholders launch a working group called ecosystem.
Our definition of the ecosystem is the following: The ecosystem is defined as a subset of people present in the human environment accompanying him/her during one or several his/her daily activities. For example, the human environment of a child consists of his or her family, friends, teachers, caregivers and so on; but his or her ecosystem as part of a school activity is composed of the teacher, specialized educators, speech therapist, psychologist and his or her fellows. The initial Norman's model does not consider explicitly such important aspect.
The paper contributes to Human-Centered Design in case of assistive interactive systems. To resume, our motivations are the following: in case of assistive interactive system design for different categories of disabled people (spoken and written disorders and behavioral disorders), the Norman's model does not reflect explicitly the importance of the ecosystem in each user's activity. Our experience in several projects shows that it must be adapted.

In consequence, this paper will report the participation of the ecosystem according with the different steps of the Norman's model. An adaptation of the conceptual Norman's model will be proposed. Two representative case studies will then illustrate the adapted Norman's model. In both cases, despite different disabilities, users have communication difficulties. Both studies are also interested in two different phases in the Norman's model. The first study focuses on the design step of prototypes, while the second focuses on the evaluation of an existing tool. These two studies thus show the crucial importance of the ecosystem whatever the design stage.

BACKGROUND

Through the 1980s, user-centered design was predominant (Norman, 1986), (Norman, 1988), (Norman, 2013). User-centered design (UCD) involves focusing on the user's needs, carrying out a task analysis, early testing and evaluation, and designing iteratively. In this approach, there is a great emphasis on the user and flexible iterative design methodology. In parallel, Norman has proposed a model of theory of action to explain how the user does things. Seven components (Figure 1) are useful in analyzing systems and in guiding system design. These seven stages are articulated according to a cycle. They are the following: forming the goal, forming the intention, specifying an action, executing the action, perceiving the state of the world, interpreting the state of the world, evaluating the outcome (Norman, 1986). It is considered that, as part of a user-centered design process, the designer should ensure that the evaluation and execution distances, in exploiting the aimed interactive system, are as short as possible, allowing intuitive use of the interactive system, facilitating its usability, see also (ISO,1998). This model is considered since the eighties as a very important a framework for reflection for the designer or the evaluator.

Figure 1. Action Theory of Norman adapted from (Norman, 1986)

Several works have examined and discussed aspects of the UCD in the Human-Computer Interaction field (dynamic diversity of users, people with disabilities, participation of the users in the design, etc.). Already in 1993, (Newell & Cairns, 1993) demonstrated the benefits of designing and researching for all “ordinary and extraordinary users”, including people with disabilities. In 2002, (Newel & Gregor, 2002) suggested the concept of “user sensitive design”. This purpose of this concept was to provide a framework for encouraging design for a much wider user and dynamic diversity. These authors also proposed that the potential user group might be expanded to include “informal as formal carers” who might not be formally the users of the system.

(Marti & Bannon, 2009) demonstrated through two case studies (design with and for children and design with and for people of differing mental abilities): “while a user-centred perspective is required at all times in the design team, the forms of participation of users in the design process needs to fit the context and can vary significantly from that presented as the prototypical UCD approach”. They also reported few possible difficulties such as “users as designers”, “limited user expressivity” in rehabilitation and assistive systems.

Ritter et al. (2014) reported the Human-Centered Design (HCD) approach that expanded the focus from the user in interaction with the interactive system. The aim of HCD is to consider how human capabilities are affected by the system beyond direct interaction with the interactive system itself. This approach suggests that “the people context of information systems must be studied and understood”. User-centered (and human-centered) design methods tend to emphasize user participation in the design process. Gulliksen et al. (2003) proposed that user-centered systems design must be defined in terms of a process where usability work and user involvement are tightly integrated with the development process. (Cockton et al., 2016) reported the integration of user-centered design in agile development in different types of case studies, but none concerns explicitly the consideration of disabled users and their ecosystem.

UCD should take into account both the full diversity of the disabilities user group and their abilities, behaviors and activities as recommended by Newell and Gregor (2002). This can affect the social human and physical environment of the disabled person. Depending on the specificities of the public, the methods and techniques of design will not be the same (Antona, Adami, & Stephanidis, 2009). For example, for an audience with communication difficulties, it is not possible to set up discussion groups, interviews or surveys and questionnaires. These tools must also be adapted, for example, brainstorming sessions with children; the duration, the course and the choice of vocabulary must correspond to the youngest. Obviously disabled end users are the people who will use these technologies. But there are others end users as well as caregivers and/or family caregivers. These have needs and expectations too for the disabled user. These needs and expectations should be taken into consideration in the design process.

In the accessibility domain (Sears & Hanso, 2012) suggested to carefully define the target user's group and determine how important characteristics of the disabled or older user population that represents the target audience will be described and considered in the design process. (Markopoulos, Timmermans, Beursgens, Van Donselaar, & Seelen, 2011) reported UCD process involving patients, rehabilitation therapists and researchers in interaction design for the design of a device for stroke patients.

In the context of the design of assistive or rehabilitation technology, the UCD approach may be unsuitable for taking into account the sensory, motor and cognitive impairments of people with disabilities. For instance, how to solicit needs from a mute person? (Vella, Sauzin, Truillet, Vial, & Vigouroux, 2015). How to adapt a questionnaire to make it accessible and to a person with cognitive disorders? What solutions can be put in place to allow users to participate in the design stages despite their difficulties (Benton, Johnson, Ashwin, Brosnan, & Grawemeyer, 2012)? Several works have proposed adaptations of the UCD method. Brock et al. (2010) adapted the participatory design of (Muller & Khun, 1993) for blind people by proposing recommendations on accessibility of the living spaces, ideas reorganization for oral presentation to facilitate the memorization, voice synthesis of oral taken, etc. Davies et al. (2004) suggested, for example, replying primarily on observations when the user (autistic in their study) has communication difficulties. Roche et al. (2014) proposed the Innovative Methodological Approach to Adapted Systemic Design (AMICAS) which aims to take into account the specificities of people with multi-disability by proposing analysis grids and aligning them. For example, user profiles are aligned with usage situations to identify which tasks users can perform and describe the difficulties encountered.

When the disabled people have communication troubles (spoken and/or written troubles), their participation in the design process can be limited or impossible. A solution is to appeal to the caregivers rather than the user himself/ herself (De Leo & Leroy, 2008). However, it is possible to combine the "user only" solution and the "proxy" solution. Frauenberger et al. (2012) name this solution "participation via proxy", that is to say, "this is when the needs of children with disabilities are represented by people with intimate knowledge of the children, such as their parents or teachers, or by educational experts". (Vella, Sauzin, Truillet, Vial, & Vigouroux, 2015) proposed that the human environment which consists in caregivers, family caregivers, friends, etc., may be involved in the UCD process to report the needs, to participate in prototyping, to customize and to evaluate the prototype. Indeed, the impairment of the user may limit the degree to which they can collaborate or express themselves appropriately their needs. The design, the deployment and evaluation of systems for disabled users, methods for eliciting needs, are relatively under-developed. As was proposed by (Marti &Bannon, 2009), we extended the concept of UCD to encompass not just the end's user but taking in the ecosystem. In this approach, the concept of end users is extended to the ecosystem of the disabled person. Indeed, needs of disabled and elderly users are accompanied daily by caregivers (family, educational staff, doctors, etc.) to carry out their activities. The activity model, as presented by (Norman, 1986) does not correspond to these observations. The activity, in this case, is not realized by the person himself/herself but by the person and his/her caregivers. One can consider that the actor of the activity is not the individual but the ecosystem.

First, for cases concerning assistive system design, the adaptation of the model of Norman's activity will be presented; this one will take explicitly into account the ecosystem of the disabled user. This adaptation will be illustrated through two case studies showing clearly the importance of the ecosystem: the first one being open to a public suffering several strokes, and the second one to a young audience with ASD (Autism Spectrum Disorders).

PROPOSITION

Our proposal aims to adapt the Norman's theory of action (Norman, 1986) by focusing on the design of systems for disabled users. Whatever his/her type of cognitive, visual, auditive, language, motor or multi impairment the disabled person may be easily integrated into a human environment (work organization, group of people, network of friends, caregivers, family …) to be included in the society.

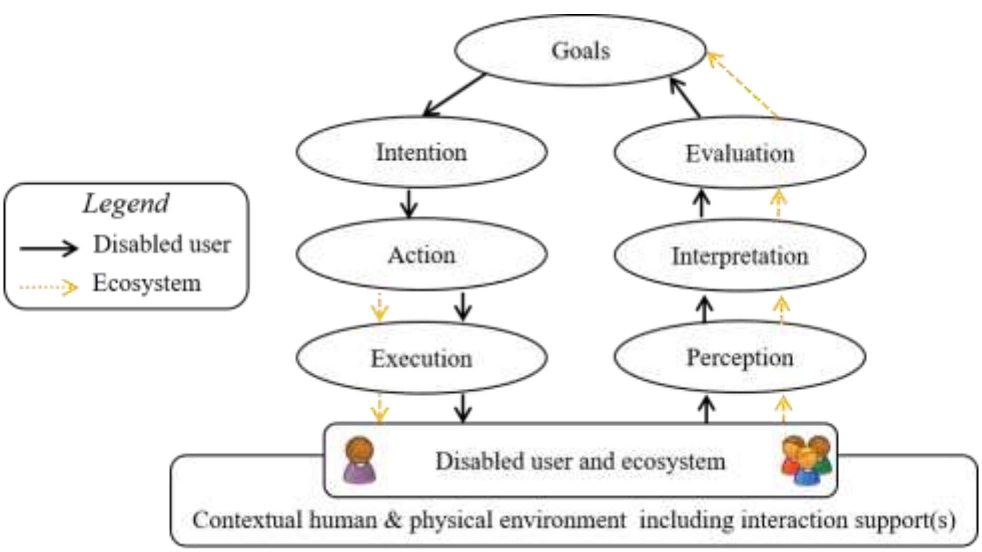

Figure 2. Adapted Action Theory dedicated to disabled user with or without accompanying people in contextual human & physical environments

The disabled person may interact with one or more interactive systems ranging from assistive technologies, rehabilitation technologies to generally information communication systems. The aim of these systems is to enable the autonomy of the disabled person during her/his daily activities (communication, leisure, transport, education, etc.). These interactive systems are considered to be integrated in their contextual physical environment (classroom, home/smart home, rehabilitation center, public transportation and so on), in the presence (or absence) of members of his/her ecosystem (Figure 2). These members may be, directly or indirectly, involved in human-machine interactions:

- The implication is direct when the concerned accompanying people are present and involved in a common activity in connection with the human-machine interaction. For instance, 1) a person with locked-in syndrome needs to express easily a request to a caregiver for help him/her in feeding or watching television; 2) the preparation of a meal is displayed on a screen, step by step, and supervised by a tutor during a cooking class with a person with a cognitive impairment.
- The implication is indirect when the concerned accompanying people are not physically present, but are concerned by the activity related to the human-machine interaction. For instance, the system will propose a daily agenda aid, reminding the care organization of a person with Alzheimer disease; in case of change in the agenda there is the necessity for the caregivers to update the information.

The model proposed in this paper must, as a framework for reflection for the designer or the evaluator, encourage analysis. The designer must consider each contextual human and physical environment involving:

- The disabled person,
- The targeted interactive system, or several systems depending on the context, for example a personal tablet and a collective interactive whiteboard,
- The role of this system in empowering the disabled person,
- The accompanying people or the different types of accompanying people, who can be involved directly or indirectly through interaction and/or assist the disabled person in his/her realization of daily activities.

In each contextual physical environment, for each activity involving the disabled user in human environment (Figure 2), it is a question of analyzing both the needs of the disabled user and the accompanying person or people involved. If the system already exists, it is also question of evaluating the ability of the system to meet the needs for all stakeholders. This analysis must be linked to the seven stages of the initial cognitive model of (Norman, 1986) in the background section. It is for this reason that Figure 2 differentiates by arrows of different colors the implication (1) of the disabled user, (2) of stakeholders of his/her ecosystem. By considering the seven stages of the Norman's model, with the assumption that the disabled user is not the only one concerned:

- Possible goals should be identified, relative to the needs of the implicated people: goals of carrying out activities, on the one hand, for the disabled user; goals of assistance or participation for doing with or doing instead of the disabled user, on the other hand, with regard to accompanying people.
- The system must be designed to support the intention. For instance, the disabled user has the intention to find a way, through the interactive system, to show his/her need for assistance, "to show he or she would like to drink". According the impairment of the

disabled person, several modes of interaction must be available, for instance, typing a textual message, selecting a pictogram (Guerrier, Kolski & Poirier, 2013) or a photograph (Allen, McGrenere & Purves, 2007) by a scanning technique, displaying a spoken message, and so on.

- The system must allow the disabled user to specify and then perform the action, while aiming for the accompanying person to be also involved. For instance, choice of the appropriate message which will be displayed by means of a text-to-speech system, easily intelligible by a caregiver of a person with athetoid cerebral palsy (Guerrier, Naveteur, Kolski, & Poirier, 2014).
- The system must help, on the one hand the disabled user, and on the other hand the accompanying person to perceive a critical situation and to interpret it. For instance to have the same information while allowing the companion to interpret that the user may be blocked by a problem of configuration, or by an interaction error.
- The system must allow the disabled user and accompanying person/people to evaluate the outcome. For instance, both of them must have a feedback from the system, error message, success message, or explanation on the status of the system during a rehabilitation session between the disabled person and the occupational therapist.

In the next section, two case studies are described. They explain how this model has been taken into account in two different contexts involving users with disabilities and their ecosystem.

CASE STUDIES

Two representative case studies will be used to illustrate how the ecosystem is taken into account through the Norman's model. These two case studies were selected because they offer two situations of disabled persons having communication disorders. The population of the first case study has spoken disorder associated to upper-limb impairment and potential visual impairment. The population of the second case study has behavioral disorders. These two case studies illustrate ecosystem implication at different steps of the Norman's model.

First case study: Disabled people with language, visual and motor impairment

The IRIT laboratory in Toulouse (France) has designed the CECI (Environment Control and Communication Integrated) system. The CECI system is an assistive technology including functions of ambient environment control as well as communication functions.

Disabled people with CECI and their ecosystem

People with motor and cognitive disabilities and little or no functional speech or written (locked-in syndrome, cardiovascular accident, head injury population) have difficulties to communicate with their ecosystem and to control alone their living environment (room in specialized reception homes or rehabilitation centers). These people generally communicate by means of a communication board of pictograms (mainly in paper form), facial expression and residual movement of the eyes, head and / or thumb, etc.

Their ecosystem consists of different caregivers (occupational therapist, speech therapist, etc.) and family members, home help medical. This ecosystem participates in the design, the learning and the customization of the CECI system.

Presentation of the CECI System

The CECI system is a visual and/or speech interface to control the ambient environment (smart home, television, radio) and to communicate through pictograms or spoken messages. The CECI user interface also permits to run identified programs such as Google, social networks, text editor, etc. All the pictograms or messages can be redefined to meet the representation of the disabled person. A user profile is linked to each CECI interface to permits the customization (type of interaction technique, type of feedback, parameter of text-to-speech system, etc.).

The CECI Design with his/her ecosystem

The CECI system is designed by a User-Centered Design including the ecosystem where the occupational therapists and family caregivers (Figure 3) are also stakeholders of the participatory design. An analysis of the residual abilities of the disabled user by means of clinical scales was conducted with the occupational therapist to determine his/her abilities (motor, spoken and visual). Then disabled user needs forms are filled out by the family caregivers and/or caregivers. For that, the caregivers ask questions when the communication is possible to patient. When the expression is not possible, the informal or formal caregivers observe the disabled user in his/her technological and human environment. To solve the problem of this limited expressivity a co-design approach is adopted involving HCI researchers and the ecosystem. Then, each two weeks, the high-fidelity iterative prototype is given to the end's user with two objectives: firstly to assess the current prototype; secondly to identify potential new needs and to customize the CECI system. The ecosystem helps and observes the behavior of the end's user. The needs are transformed into functions of the CECI system with the SoKeyTo application (Sauzin, Vella, & Vigouroux, 2014).

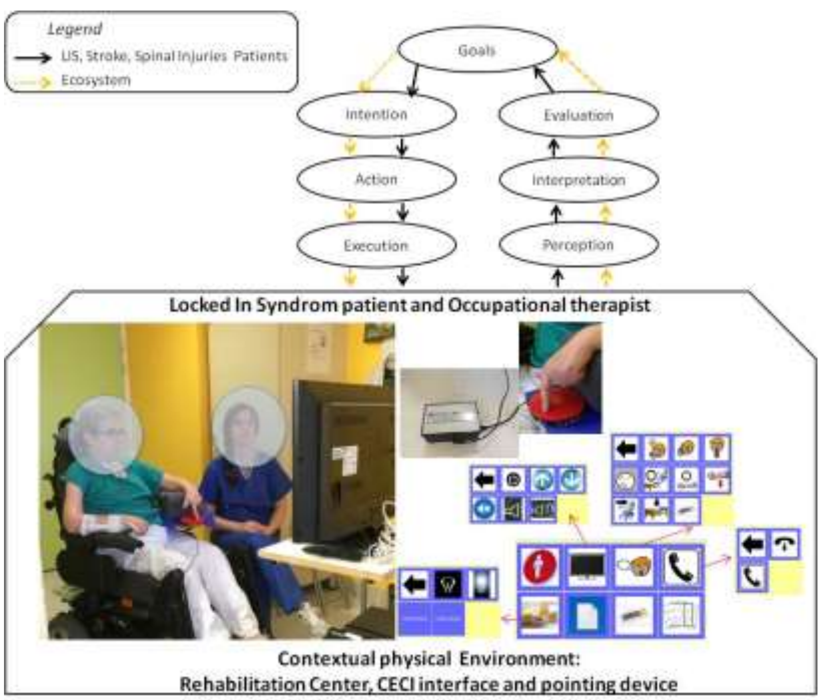

Figure 3. Disabled patient and Occupational Therapist (left), Principal screen of CECI user interface (right)

The principles of the Norman's model were respected as soon as possible. For instance, the affordance of the functions pictograms (Figure3) is crucial to aid the Action and Execution activity. The designers in collaboration with the ecosystem have preferred to give priority to action solution because the visible buttons act as a direct translation into possible actions. The ecosystem (occupational therapist have suggested to the designers to define three types of pointing (pointing, dwell clicking, scanning) with a throwing switch. Evaluation activity is possible through visual and audio feedback of what was selected as action. These two types of feedback have been suggested by the occupational therapist. Visual structure and organization in levels of the interface have been also designed to aid the Interpretation Activity. This structure is iteratively defined through trials done by the designers and the caregivers.

Implication of the ecosystem in the customization and the appropriation of the CECI system

The participation of the ecosystem is important during the learning phase of the CECI user interface. The occupational therapist is going the seven stages of the Norman's model during the learning phase of the CECI interface. Progressively the disabled person will be able to realize alone these stages. Another essential participation is the contribution of the occupational therapist who will define in close collaboration the representative pictogram to represent the intention during the customization of the CECI interface. His/her participation is crucial for the interpretation and evaluation stages for a rehabilitation task. When the participation of the ecosystem is null, the disabled people is completely autonomous in the use of his/her assistive technology.

Second case study: young people with autism disorders

In this part, the authors present a research work carried out by CREN laboratory in Le Mans (France). The team worked with a young audience with ASD (Autism Spectrum Disorder) as part of the R&D project "çATED – Autism"[1]. The aim was to design and experiment a digital agenda running on tablet (Guffroy, 2017).

Young people with ASD and his or her ecosystem

The public with ASD is identified by a set of specificities commonly presented as autistic triad; a restricted, repetitive and stereotypical character of behavior, interests and activities (American Psychiatric Association, 2013), (WHO, 2010). It also shows qualitative alterations of social interactions and communication. Its specificities don't allow the children with ASD to indicate, alone, his or her preferences or encountered difficulties with the tool (De Leo & Leroy, 2008). To overcome these difficulties, young people with ASD are daily surrounded by a varied human environment composed of different caregivers and accompanying persons: family members, medical teams or educational teams for example. These different ecosystems allow this specific audience to benefit from a "human" interface with the world. This study is interested in the evaluation of an application used in the school context, the ecosystem concerned is the teaching team (teacher and caregivers).

---

[1] "çATED – Autism": The title of the project may be translated by "That helps you - Autism"

Application çATED

çATED application allows a simplified time management based on tools commonly used by children with ASD: pictograms and timer (Figure 4). The children, accompanied or not by their caregivers (parents or teachers in specialized school for the case study), record their schedule in the application on tablet. Whenever a new task begins, the children are warned. They can then visualize, with the timer, the time left to finish the activity. This allows them to apprehend their day more serenely. They know what they have to do, in what order, and how long. The principle is to involve both the disabled children themselves and their human ecosystem in time management.

Implication of the çATED ecosystem in the Norman's model

The study reveals the involvement of disabled children and their ecosystem at two levels: in the appropriation and use phases, and in the evaluation and the re-design of the application.

<u>Appropriation and use phases</u>

Before the evaluation phase, the application was made available to children to learn how to use it and appropriate it. The engineer was present half a day a week (for two months) to support the children and their school ecosystem (the teacher and the two caregivers) in this phase of learning and thus establish a climate of trust with the students.

The children quickly mastered the tool, sometimes explaining to the teaching team how to do it.

The availability of the application in classroom changed the behavior of the children and of the teaching staff with respect to classroom organization. Before the introduction of the application, to pass from one activity to another, the teaching team had to manage the time and sequence of activities for each student. The use of this digital timetable is now managed by the child, with the support of caregivers when necessary. çATED application provides feedback that allows children and caregivers to get on with the tasks they need to do (perception aspect in the Norman's model). The application sends a notification to signal the end of one activity and the start of the next one. For example, when a "free session" begins (children are free for 20 minutes to do what they want), children perceive in parallel the notification. Both children and caregivers perceive the information: visually and audibly through the application or because the students are agitated. However, the assessment of what they have to do differ. Children understand that they change their activity and therefore of material and / or place. The caregivers, meanwhile, finalize the activity (for example, pick up the homework) and prepare the next school activity. They understand that this activity begins. If they want to play together, they must organize themselves (Figure 4). Then, they use the application to manage this common time slot. If the next school activity takes place in another classroom, the child then reports it to the caregiver so that he/she can accompany her/him.

The application helps to keep track of the school's schedule. Children are more autonomous and no longer need to ask adults what to do. And the teaching team has more time to set up school activities.

<u>Evaluation and re-design of the application</u>

After the appropriation phase, children and ecosystem participated in the evaluation phase of the application with the engineer. The observation of the children in situation was realized at different levels: during individual working sessions on the application and during daily observations. In the first case, during twenty-minute sessions, the engineer observed each student using the application (the student had to enter his or her own schedule). During these sessions, children could comment on the activity and ask for help from the engineer (often it was mainly to validate the work done). In the second case, the ecosystem, composed by teacher and caregivers, has itself observed the students using the application on a daily basis. They answered and helped the children in case of difficulties. All the problems encountered and observations were recorded in a liaison booklet (This booklet was freely available to the entire class; children were also able to note information).

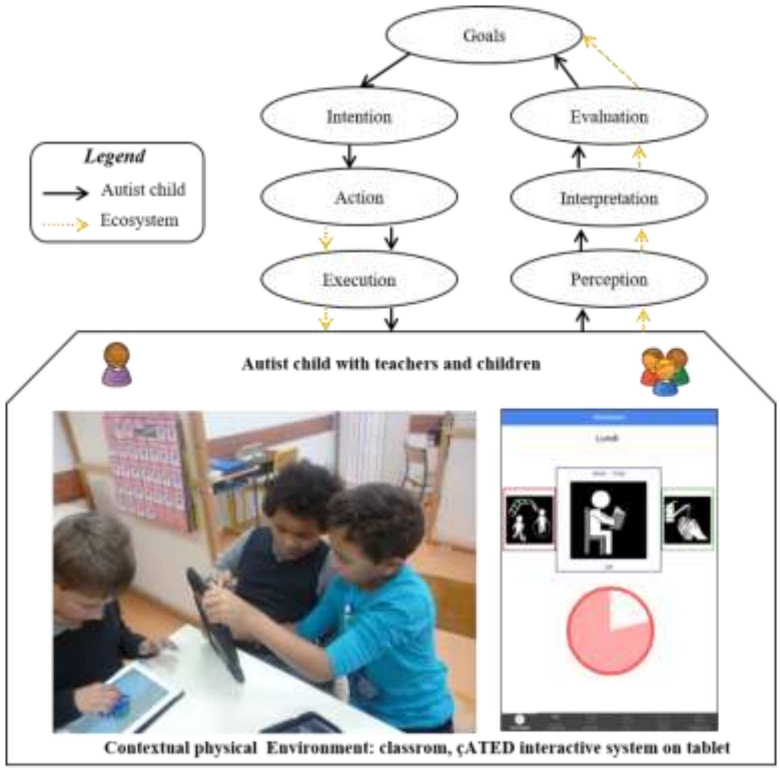

Figure 4. Children use the application collectively (left); Principal screen of çATED application (right),

Regularly, meetings were scheduled between the engineer and the ecosystem to centralize all the information collected. Each of the parties can comment and argue the observations. The expertise of each one thus allowed to improve and to consolidate the returns. From the analysis of collected returns, it turned out that the type of statements was related to the person who had collected them. The children's feedback focused mainly on the visual aspect of the application (aesthetics, placement and size of components) criticizing sometimes by referring to the visuals they were used to with other tools. The teaching team provided information on the workload, the homogeneity and the coherence of the task. This information was based on its knowledge of the public, like for example the fatigue that the children can have to perform this type of activity. The engineer, meanwhile, provided information on guidance and error management. This case study highlights the legitimacy of each of the actors during the prototype evaluation stage: the children (disabled users) and their ecosystem (composed by teacher and caregivers). If one of them is missing from this evaluation approach, then the information collected is incomplete.

After this evaluation phase, the application has been updated. This new version was also evaluated in the same class, in the same way. Observations showed that children made fewer mistakes and were quicker to enter their schedules. Feedback from the first evaluation was therefore consistent.

DISCUSSION

The proposed model provides a different view of Norman's original version from the 1980s (Norman, 1986); (Norman, 1988), as well as of his following publications (see, for example, (Norman, 2013)). For disabled people, the role of ecosystem stakeholders is crucial. These stakeholders are indeed direct or indirect users of the interactive system in different physical and human environments, in various contexts. It is therefore important that designers and evaluators have a new framework for thinking about this. Such a framework had not yet been proposed in the literature. There is no trace of this in Norman's work, in the ISO standard, or in the description of user-centered methods, whether or not related to the field of disability (see works cited in the Background section).

The two case studies (CECI system and çATED application) demonstrate that the adaptation of the Norman’s by taking into account the ecosystem is efficient for the design of interactive systems for the disabled people. Both case studies demonstrate also that the ecosystem has played an important role in all phases of design whatever the type of system, assistance, education or rehabilitation. According to the type of interactive systems the stakeholders of the ecosystem may be different: caregivers, teachers, specialized educators, occupational therapists, speech therapist, and psychologist. Indeed, the ecosystem has played an important role in the expression of needs, recommendations of customization and learning phase. This information covers all the stages of the proposed model.

After an appropriation phase, the disabled person needs less support from the ecosystem to use his/her assistive technology, his/her digital application or to do his/her rehabilitation. This gradual erasure of the intervention of the actors of the ecosystem is dependent on the severity of the disability and on the degree of appropriation of the interactive system. If the disabled person becomes autonomous in the use of the digital application, the ecosystem then could disappear from several of the stages visible in the adapted Norman’s model.

However, the participation of the stakeholders is different according to the stages of the adapted Norman’s model:

- In the CECI system, the role of occupational therapists is different. For the Intention, Action, Execution stage, he/she expresses needs and gives instructions for the learning of the assistive technologies; for the Perception, Interpretation and Evaluation stages, he/she verifies if the goal has been achieved.
- In the çATED environment, the role of the teaching team is to support children in their school learning and autonomy learning. The teachers help children in school activities but also in their planning. The caregivers express the needs and instructions for learning. Then they check that the goal is reached. Caregivers provide support in children's activities both physically and cognitively. The cooperation is complete between them.

CONCLUSION

Generally speaking, the challenge of digital applications is to offer effective interactive means while being intuitive and ergonomic to the user. It is about reducing the distance (physical and cognitive) that can exist between the user and the system he or she controls. But these needs are particularly crucial for end users with disabilities because their inclusion in the world often depends on the interactive capabilities of the digital systems they are offered. The engineering challenge is to design interactive systems that are both adapted to disability and both an instrument of inclusion in society and the rest of the world.

The UCD participatory design methods do not fully achieve these objectives because they are user-centred and do not take into account the functional and human context in which the person with disabilities evolves. This article has shown that the human ecosystem that surrounds the disabled person must be taken into account in the analysis of the activities carried out by the person through the digital system. Members of this ecosystem know the specificities and needs of users "in context". The initial Norman's conceptual model, which represents the seven phases of the action-evaluation loop, has been adapted to reflect this ecosystem. In the proposed adapted version, each phase of the interaction cycle takes into account both the activity of the disabled person and the activity of the members of the surrounding ecosystem. Two case studies illustrated this proposal in two different instrumentation contexts: an interactive customizable system dedicated to multi-stroke population and a tablet-based digital agenda for a young audience with autism spectrum disorders. In both cases, the members of the ecosystem are present and available to assist the person in his or her circular activity of evaluation of the situation and decision on the action to carry out. This intervention of the ecosystem is gradually reduced thanks to the autonomy gained by the disabled stakeholder as he or she uses the interactive system. The discussion showed that the adapted Norman model plays its role of framework for reflection for the designer (including expression of needs, prototyping and evaluation stages) of interactive systems dedicated to disabled people. The discussion also showed that the initial Norman model is consolidated by this conceptual adaptation.

The perspectives of this research focus on the extension of Norman's conceptual model for other disability situations. It is about integrating the role of the ecosystem into the design of interactive systems. Implementation situations may concern memory loss pathologies for Alzheimer patients, or the adaptation of web pages for elderly people and dyslexic children. In particular, it will be necessary to analyze the phases of Action and Execution in relation to the ecosystem.

ACKNOWLEDGMENT

Authors thank all the disabled persons and all stakeholders of ecosystems who participated in the two case studies reported. They thank also the reviewers for their numerous constructive remarks.

REFERENCES

Allen, M., McGrenere, J., Purves, B. (2007). The design and field evaluation of PhotoTalk: A digital image communication application for people with aphasia. In Proc. ASSETS' 07, October 15-17, 2007, Tempe, Arizona, USA.

American Psychiatric Association. (2013). DSM-V (American Psychiatric Association).

Antona, M., Ntoa, S., Adami, I., & Stephanidis, C. (2009). User Requirements Elicitation for Universal Access. Stephanidis, C. (Ed.). (2009). *The universal access handbook*. CRC Press

Benton, L., Johnson, H., Ashwin, E., Brosnan, M., & Grawemeyer, B. (2012, May). Developing IDEAS: Supporting children with autism within a participatory design team. *In Proceedings of the SIGCHI conference on Human factors in computing systems* (pp. 2599-2608). ACM.

Brock, A., Vinot, J. L., Oriola, B., Kammoun, S., Truillet, P., & Jouffrais, C. (2010, September). Méthodes et outils de conception participative avec des utilisateurs non-voyants. *In Proceedings of the 22nd Conference on l'Interaction Homme-Machine* (pp. 65-72). ACM.

Cockton, G., Lárusdóttir, M., Gregory, P., & Cajander, Å. (2016). Integrating User-Centred Design in Agile Development. *In Integrating User-Centred Design in Agile Development* (pp. 1-46). Springer International Publishing.

Davies, R., Marcella, S., McGrenere, J., & Purves, B. (2004). The ethnographically informed participatory design of a PD application to support communication (No. 77-78, pp. 153-160). ACM.

Frauenberger, C., Good, J., & Alcorn, A. (2012, June). Challenges, opportunities and future perspectives in including children with disabilities in the design of interactive technology. *In Proceedings of the 11th International Conference on Interaction Design and Children* (pp. 367-370). ACM.

Guffroy, M. (2017, april). *Adaptation of evaluation methods in the design of a digital application for a young audience with autism spectrum disorders* (in french). PhD Thesis, University of Le Mans, France, Consulted to http://www.theses.fr/s84867

Gulliksen, J., Goransson, B., Boivie, I., Blomkvist, S., Persson, J., & Cajander, Å., (2003). Key principles for user-centred systems design. *Behaviour & Information Technology*, 22 (6), 397-409.

Guerrier, Y., Kolski, C., & Poirier, F. (2013, September). Towards a communication system for people with athetoid cerebral palsy. *In IFIP Conference on Human-Computer Interaction* (pp. 681-688). Springer, Berlin, Heidelberg.

Guerrier, Y., Naveteur, J., Kolski, C., & Poirier, F. (2014, July). Communication System for Persons with Cerebral Palsy - In Situ Observation of Social Interaction Following Assisted Information Request. *In International Conference on Computers for Handicapped Persons* (pp. 419-426). Springer, Cham.

ISO, I. (1998). 9241: *Ergonomic requirements for office work with visual display terminals*-Part 11: Guidance on usability. ISO, Geneva.

De Leo, G., & Leroy, G. (2008, June). Smartphones to facilitate communication and improve social skills of children with severe autism spectrum disorder: special education teachers as proxies. *In Proceedings of the 7th international conference on Interaction design and children* (pp. 45-48). ACM.

Markopoulos, P., Timmermans, A. A., Beursgens, L., Van Donselaar, R., & Seelen, H. A. (2011, August). Us' em: The user-centered design of a device for motivating stroke patients to use their impaired arm-hand in daily life activities. *In Engineering in Medicine and Biology Society, EMBC*, 2011 Annual International Conference of the IEEE (pp. 5182-5187). IEEE.

Marti, P., & Bannon, L. J. (2009). Exploring user-centred design in practice: Some caveats. *Knowledge, technology & policy*, 22(1), 7-15

Muller, M. J., & Kuhn, S. 1993. Participatory design. *Communications of the ACM*, 36(6), 24-28.

Newell, A. F., & Cairns, A. Y. (1993). Designing for extraordinary users. *Ergonomics in Design*, *1*(4), 10-16.

Newell, A. F., & Gregor, P. (2002). Design for older and disabled people–where do we go from here?. *Universal Access in the Information Society*, 2(1), 3-7.

Norman, D.A. (1986). Cognitive engineering. In D.A. Norman & S.W Draper (Eds.), User centred system design: new perspectives on human computer interaction. Hillsdale, NJ: Erlbaum, pp. 31-61.

Norman, D. A. (1988). *The psychology of everyday things*. New York: Basic Books.

Norman, D. A. (2013). *The design of everyday things: Revised and expanded edition*. Basic Books (AZ).

Phillips, B., & Zhao, H. (1993). Predictors of assistive technology abandonment. Assistive technology, 5(1), 36-45.

Riemer-Reiss, M. L., & Wacker, R. R. (1999). Assistive Technology Use and Abandonment among College Students with Disabilities, 3 (23). IEJLL: *International Electronic Journal for Leadership in Learning*, 3.

Ritter, F. E., Baxter, G. D., & Churchill, E. F. (2014). *Foundations for designing user-centered systems: what system designers need to know about people*. Springer Science & Business Media.

Roche, A., Lespinet-Najib, V., & André, J. M. (2014, July). Development of a pedagogical aid tool for pupils with multiple disabilities: setting up a systemic design method. *In Congress of applied Psychology*. UCAP 2014.

Sauzin, D., Vella, F., & Vigouroux, N. (2014). SoKeyTo: a tool to design universal accessible interfaces. *In Proceeding of International Conference on Applied Human Factors and Ergonomics* (AHFE 2014) (pp. 659-670). Poland.

Sears, A., & Hanson, V. L. (2012). Representing users in accessibility research. ACM Transactions on Accessible Computing (TACCESS), 4(2), 7.

Vella, F., Sauzin, D., Truillet, P., Vial, A., & Vigouroux, N. (2015, March). Co-design of the Medical Assistive and Transactional Technologies system. *In Journées RITS 2015* (pp. pp-122).

WHO (World Health Organization). (2010). *ICD10 (International Classification of Diseases).*